Things of science

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SURFACE TENSION

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This unit contains three kinds of capillary tubes, steel needle, wire mesh, length of wire, colored tooth picks, drinking straw, piece of plastic and this explanatory booklet.

Most of us think of water as something to drink when we are thirsty, wash ourselves with or swim in during the hot summer months. Have you stopped to think, however, why rain rolls off water repellent raincoats or why water is so quickly absorbed by a towel? Most of you have probably observed mosquitoes or tiny water insects alight on the surface of a pond or creek and walk or skim around on the water. What makes this possible?

The experiments in this unit will answer these questions for you and will help you understand some properties of water due to the molecular forces.

First identify the objects in your unit.

ROUND CAPILLARY TUBING—Larger size; 1.4—1.5 mm. internal diameter (I.D.).

ROUND CAPILLARY TUBING—Smaller size; 1.1—1.2 mm. (I.D.).

FOUR-BORE CAPILLARY — Composed of four fine capillary tubes.

WIRE MESH—Insect screen made of aluminum.

STEEL WIRE—Pliable wire; has many uses.

WATER-REPELLENT PLASTIC—3x5-inch sheet.

COLORED TOOTHPICKS—The vegetable color is soluble in water but will not affect the experiments.

DRINKING STRAW—Made of cellophane plastic.

NEEDLE—Produced from fine steel.

COHESION AND ADHESION

All the objects around you, telephone, vase, pencil or paper, are held together in their respective shapes by the attractive forces between the molecules of the substances of which they are made. The stronger these forces are, the more solid the material.

Water, like solids and other liquids, is also held together by molecular forces. However, the attractive forces between the molecules in liquids are not as great as they are in solids. Thus, water does not retain a definite shape independently, but assumes the shape of the container in which it is held. Or if free, it spreads out under its own weight.

Molecular forces within liquids are

responsible for certain characteristic properties of water which will be revealed to you through the experiments in this unit.

In a container, the water molecules are attracted equally on all sides by other water molecules. This attractive force of like molecules for each other is known as the *cohesive* force. Water molecules may also be attracted by molecules other than water molecules and this attraction of unlike molecules for each other is known as the *adhesive* force.

Experiment 1. Sprinkle water on a piece of wax paper or on an oiled surface. Does the water spread over the surface or form into droplets? Why doesn't the water stick to the paper? This is because the attraction of the water molecules for each other is greater than for the wax molecules on the wax paper. In other words, the cohesive forces are greater than the adhesive forces.

Now push one droplet against another. Observe what happens. The drops act as if they are drawn to each other. What is the attractive force that pulls water drops together to form bigger ones?

Now tip the wax paper slightly and the droplets will roll off the paper. Feel

the paper. Is it wet or dry? Since the force of the attraction of the water molecules is greater for each other than for the wax paper, the water did not adhere to or wet the paper.

The same principle shown here applies to the water repellent raincoat. Rain does not wet the material because the fabric has been treated with a substance that does not attract water molecules.

Experiment 2. Have you ever wondered why drops of water are round? The molecules in a liquid are continually pulling on each other trying to occupy the smallest possible space. Geometrically the most compact form a liquid can take with the smallest possible surface area is a sphere. Thus when a liquid is free to take any shape it can with no outside forces acting upon it, it will assume a spherical one. Falling drops of water of a sufficiently small size take on a spherical shape.

Look at the drops of water on the wax paper. Are they perfect spheres? You will see that they are not completely round. Because of gravitational forces liquids on a surface tend to take on a flattened form. However, since the force of gravity on an object becomes weaker as the object becomes smaller, you will

see that the smaller the drops of water are, the more spherical they are.

Tiny drops of mercury will form perfect spheres on a flat surface because the cohesive forces within mercury are much greater than in water and counteract the gravitational pull.

Experiment 3. Take the drinking straw and suck up some water into it. Hold your finger tightly over one end of the straw to retain the water in it. While holding the straw in a vertical position, gently pinch the straw and allow the water to drip slowly from it. You will now see how a water drop is formed. As it grows it assumes a rounded shape. Adhesive forces between the molecules of water and the straw cause the drop to cling to the edge of the straw and it becomes elongated until it drops by its own weight, assuming a tear drop shape as it falls. If the distance of fall is great enough it will become perfectly round. An example of this are the drops that fall from a garden water sprinkler.

Drop formation can also be observed in a slowly dripping faucet.

Lead shot is made by applying these principles. The round shot is formed from molten metal as it falls through the air.

Experiment 4. The following experiment will demonstrate the fact that liquids when free to take on any shape will form a sphere. Half fill a glass with water. Place several drops of olive oil or salad oil on the surface of the water and notice how it spreads out. The cohesive forces within the oil are not very great and the gravitational pull causes it to spread out in a thin film if the energy of the system is not increased by this action.

Slowly add rubbing alcohol by pouring it carefully down the sides of the glass. Keep your eyes on the oil and observe what happens. Because of the condition of minimum energy, the oil forms into a perfect sphere.

Experiment 5. Dip a glass into water. Does the water wet the glass? The attraction between the water molecules and glass molecules is greater than the attraction of water molecules for each other causing the water to stick to the glass.

Take a wax candle and do the same. What happens in this case? What are your conclusions?

If you take two flat pieces of glass, such as microscope slides and wet them and place them in contact flat against each other, you will find it quite difficult to

pull them apart because of the strong adhesion of water to glass. Sometimes they can be separated only by sliding apart.

Adhesion is clearly demonstrated in glues where the attraction of unlike molecules is very much greater than that of like molecules, permitting you to paste pictures in scrapbooks or mend furniture. How strong this adhesive force can be is shown by epoxy glue, where once the components are placed in contact, the adhesive force between the molecules is so strong they form an inseparable bond.

Experiment 6. Partly fill a glass with water. The water is level except at the point of contact with the glass. Because water adheres to glass, or wets it, it clings to the sides of the glass rising slightly above the level of the water forming a concave surface upward. (See Fig. 1.)

If mercury is used instead of water, the edges will curve downward in the glass forming a convex surface as shown in Fig. 2. Since mercury does not adhere to glass, the cohesive forces within mercury pull the molecules down toward the center to occupy the smallest possible area, forming the curved surface, just as you have already observed in the drops of water on the wax paper.

CAUTION: If you should experiment with mercury, remember it is **POISONOUS.**

Line a glass with wax paper and partly fill with water. Does the water curve concave upward or convex downward along the edges?

There are many examples of adhesion in our daily lives. Some are troublesome, like mud on your boots and dirt on your hands, but others are more or less a necessity, such as adhesive tapes for bandaging and mortar to hold bricks together. Look around you for other examples.

The cohesive forces within liquids result in the property of liquids known as *surface tension.*

SURFACE TENSION

The phenomenon of surface tension is an important property of liquids that plays a very active role in our lives although many of us are not aware of it or do not give it much thought.

The usefulness of soaps and detergents for cleansing is due to their ability to weaken the surface tension of water. Antifoams that reduce surface tension and prevent foaming are important in many industrial processes. The efficiency

of lubricating oils for motors depends upon their surface tension.

What is surface tension? You have done experiments demonstrating the cohesive forces in water and how liquids behave because of the attraction of like molecules for each other. The drops of water on the wax paper were held together by surface tension resulting from cohesive forces.

If you place water in a glass, the water molecules are attracted to each other equally on all sides and pull the molecules toward the center. However, at the surface the pull is downward and horizontal only, since there are no water molecules above to pull other water molecules upward. The cohesive force between the molecules at the surface causes them to form a layer of molecules that act like a thin elastic membrane. This tendency of the surface of a liquid to contract and act like an elastic film is known as surface tension.

If you have ever sat beside a running brook or creek, you may have marveled at drops of water bouncing along on the surface traveling for perhaps a foot or so before coalescing with the flowing water. Surface tension makes such a phenomenon possible, the water surface

acting as an elastic membrane for the bouncing drops.

Experiment 7. Surface tension can be demonstrated in many ways. Fill a glass with water. By gently placing the needle from your unit on the surface of the water you can make it float. This can be done by means of forceps or tweezers. If you do not have either of these, take a short length of wire and turn up both ends to form a cradle for the needle as shown in Figure 3. By placing the needle on the curved ends of the wire and gently lowering it on to the surface of the water the needle will float. Still another very simple method is to place the needle on a thin piece of paper and then lower them together on the water. Carefully remove the paper from beneath the needle which will remain floating.

What makes it possible for an object which obviously has a density much greater than water to float? The answer is surface tension. The needle is light enough so that the force of the surface tension will hold it up.

Experiment 8. Look horizontally across the surface of the water and you will see that it is depressed on each side of the needle. The weight of the needle has stretched the surface film of the water,

Fig. 1

Fig. 2

Fig. 3

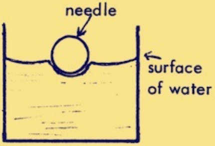


Fig. 4

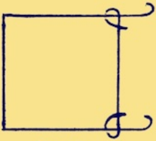
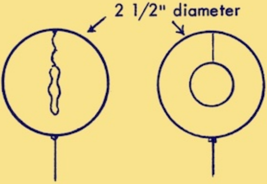


Fig. 6



Figs. 5 - 5a

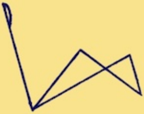


Fig. 8

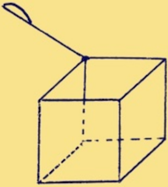


Fig. 7

Fig. 9

Fig. 10

but not enough to break it. (See Fig. 4).

Float a double-edged razor on the water. Notice again the depression along the edges of the razor. The cohesive force in water is strong enough to support even an object of this size.

Try to float other metal items such as paper clips on water.

Mosquitoes and other tiny insects can rest on or skim across the surface of ponds because of surface tension. They are light enough to be supported by the elasticity of the surface of the water.

Experiment 9. Certain substances reduce the surface tension of water. Float the wire screen from your THINGS unit carefully on the water. Observe that the surface tension prevents it from sinking although it is heavier than water.

Drop a small amount of soap or detergent, either liquid or powder, on the floating wire screen. What happens? The surface tension has been weakened by the detergent or soap and the weight of the screen causes it to sink to the bottom. A very quick reaction is achieved by using a concentrated liquid detergent.

Soaps and detergents by reducing the surface tension of water make the water "wetter" and more adhesive. It is this

quality of soaps and detergents that makes them useful for cleaning purposes. Garden sprays mixed with detergents are more effective since weakening the surface tension allows the solution to spread over a greater area and adhere more readily to the foliage.

Heat also reduces surface tension. For this reason washing in hot water is more effective than in cold.

Experiment 10. Rinse and dry the screen and float it on water again. Pour some alcohol on the screen. From your results does alcohol reduce the surface tension of water?

Experiment 11. Test the strength of surface tension. Dry the screen and float it in a container of water. Place a small object, such as a paper clip carefully on the screen. See how many paper clips the screen will support. You will find that the surface tension of water is surprisingly strong.

Experiment 12. Take a piece of wire about six inches long and bend into an L-shape.

Fill a glass beaker or other container with water. Placing your eyes level with the surface of the water lower one edge of the wire form into the water. Lift it up slowly and as you raise it above the

surface you will observe that you are pulling up against the tension of two surfaces, one on each side of the wire.

Surface tension can be measured by noting the force required to stretch a film of water from the surface until it breaks. An instrument making use of a rectangular wire form can be used to measure the surface tension of liquids, which is expressed in dynes per centimeter, according to the following equation,

$$T = \frac{F}{L}$$

where T is the surface tension, F the force required to stretch the film of water until it breaks and L the length of wire. However, as you have just observed force is exerted against two films as the wire is raised above the surface of the water and the equation is modified to

$$T = \frac{F}{2L}$$

In constructing a surface tension apparatus, a Joly spring type balance is usually used.

By means of such an instrument the surface tension of various liquids has been measured and comparision tables compiled.

Experment 13. Try floating a needle on alcohol. On salad oil. What are your results and conclusions?

Experiment 14. Take a flat dish and hold it under rapidly running water. The film-like sheet of water that extends from the edge of the plate is the result of surface tension.

Take the piece of plastic sheet in your unit and hold it under a slowly running faucet. Notice how the water forms into a narrow stream and wriggles back and forth over the plastic surface. Since water does not adhere to the surface and is free to take its own path it moves about the plastic sheet. Surface tension holds the water together in a small stream.

Experiment 15. Fill a glass partly full of water. Now gradually add more water carefully filling the glass to the top. By means of an eye dropper or your drinking straw add water drop by drop and you will see the water level rise above the rim of the glass forming a convex surface along the edge. The water adheres to the edge of the glass and surface tension prevents it from spilling over. See how much water you can add until surface tension is overcome.

Carefully take a teaspoonful of water from the glass. Note how high above the

edge of the spoon the water rises. The convexity of the surface of the water is more apparent here. Can you get an exact teaspoonful of water?

Experiment 16. Sprinkle some talcum powder or ground pepper on the surface of a container of water. Place the soaped tip of a toothpick in its center. What immediately happens? Surface tension has been reduced at the point of contact of the soaped toothpick but not in other areas and the molecules of water are pulled in the direction of greater force, drawing the talcum powder along with them away from the center.

The colored toothpicks were contributed by the Diamond National Corporation, Diamond Match Division, New York.

Experiment 17. Take the two other toothpicks from your kit and float them in a bowl of water. Touch the soaped tip of the toothpick to the water between them. What would you expect to happen? Can you explain the results?

Repeat the experiment with alcohol. Place a few drops of alcohol between the toothpicks and note the results.

Naphthalene also reduces surface tension.

Experiment 18. Float the two toothpicks in another glass of water fairly close

to each other. The toothpicks will be drawn toward each other and cling together. Can you explain the results in the light of what you have observed in the previous experiments?

For the following experiments purchase a bottle of commercial soap bubble liquid or use some liquid dishwashing detergent. The latter makes excellent long lasting soap bubbles.

The elastic nature of surface films and surface tension can be well-illustrated by means of soap bubbles and soap films. Soap films like other liquid surfaces are elastic and contract to try to occupy the smallest possible space. For this reason, soap bubbles, when free to take any shape, are round.

Experiment 19. Cut a 10-inch piece of wire from your wire sample. Make a circular loop about 2½ inches in diameter hooking the loose end around to make as smooth a circle as possible. Use the extra length as a handle.

Next tie a looped thread to the wire ring as illustrated in Figs. 5 and 5a. Dip the ring into a soap bubble solution to form a thin film. Touch the center of the loop with a heated tip of wire and observe what immediately happens. The force of the surface tension of the soap film out-

side the center loop draws the thread out to form a circle.

Experiment 20. Now take two wire rings shaped like the one in Experiment 19 and place them together in the soap solution. Draw them apart and a film will form from one ring to the other. Notice its shape. Stretch this film and contract it. Observe how the film finally separates into two films.

Experiment 21. Shape a piece of your wire into a two pronged form as shown in Fig. 6. Take a short straight piece of wire a little longer than the width between the prongs and loop each end of this wire loosely over them. Bend back the free ends of the prongs so that the short cross strip will not slip off. Keeping the strip of wire near the ends of the prongs, dip the device into soap bubble solution to form a soap film stretching across the rectangular shape. Let go the cross strip and notice how far the strip is pulled. Surface tension of soap film can be measured by a calibrated instrument constructed similar to this device.

Experiment 22. Keeping the wire cross strip about a quarter of an inch from the base of the prongs form a soap film across this area. Pull the strip care-

fully to the end of the prong being careful not to break the film. Release the strip and see how quickly it springs back to the base.

Experiment 23. Soap films tend to contract to occupy the smallest possible space as demonstrated by the previous experiments. As a result of this tendency many beautiful and interesting shapes can be formed by constructing various geometric shapes with wire. Construct a cube frame with your wire extending one end as a handle and dip in soap solution. You will have a beautiful cube within a cube formation. Think of other geometric shapes such as triangles and circles and make frames of these and see what variety of designs you can produce. (See Figs. 7 and 8.)

CAPILLARITY

Surface tension and adhesion act together to produce another characteristic property of liquids, *capillarity.* As you have already observed, water in a glass container will rise up a little at the sides forming a concave surface upward. In a narrow tube the whole surface of the water becomes concave as a result of surface tension. This curved surface is referred to as the meniscus.

In experimental work when reading the height of a column of liquid in a calibrated tube, the lowest part of the concave surface, or the lower meniscus, is read. If the column is mercury, the meniscus will be convex and in this case the highest part of the meniscus, or the top of the convex surface, is taken for the reading. (See Figs. 9 and 10.)

If you should take a narrow glass tube and place it upright in water, the water will rise up the tube by the combined action of adhesion and surface tension. The water adheres to the sides of the tube and the contractile force of surface tension draws the water up the tube. When the weight of the water and the upward forces are equalized the water will stop rising. This is known as capillary action, or capillarity.

If mercury is used, it does not rise up the capillary tube, but is depressed below the surface.

Experiment 24. Examine the capillary tubes in your box. Since they are very fragile, handle them carefully.

Using the piece of plastic sheet in your unit as a backing mount the three tubes on this with scotch tape in order of size, about one half inch apart. Allow about a

half inch of each tube to protrude beyond the edge of the backing.

Experiment 25. Make a colored solution of water by using vegetable dye or ink. Make the color quite dark to better observe the capillary action.

Watching the tubes closely, lower them into the colored water. In which of the tubes does the liquid rise the highest?

According to the law of capillary action, the height to which a liquid rises in a capillary tube varies inversely as the radius of the tube. In other words, the smaller the diameter of the capillary tube the higher the liquid rises in the tube. Do you find this true?

The water should rise highest in the four-bore tubing.

Remove the four-bore tube and lower it as far as you can into the water, while still keeping the top end above the surface. Does it overflow? Lower the other two tubes down into the water in the same way. The water rises to the top of the tubes and is held there. No matter how short the tube extending above the surface of the water, surface tension prevents the water from escaping from the top of the capillary tube.

Experiment 26. Vary the depth of the two round tubes in the colored water,

lowering and raising them. Does the height to which the water rises in the tube change? Regardless of how deep the tubes are lowered into the liquid the height of the water in the tubes will remain the same if free to rise to the fullest extent. Why?

Experiment 27. Lift the tubes out of the water. Does the water remain in the tubes? Can you shake it out?

The adhesion of the upper and lower surfaces of the water to the glass and the contractile forces of both surfaces tend to hold the liquid in the tubes. From which tube is the water most difficult to remove? Why?

Capillary tubes have a wide variety of uses as containers for vaccines, blood-coagulation time rate determination, boiling and melting point determination, providing wide bearings for moving parts and for electronic components.

Experiment 28. Capillary action can be observed around you. Dip the end of a bath towel into a basin of water and let it stand for a while. Soon the whole towel will be wet. This is the result of

capillarity. Sponges soak up water for the same reason. Can you explain why water is retained by the sponge until it is squeezed out?

Plants and trees receive much of their required moisture as a result of capillary action. The water rises in the soil by capillarity and is held there.

Think of other examples.

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